Fundamentals of Asset Management

Step 2. Assess Condition, Failure Modes

A Hands-On Approach

Tom’s bad day…

First of 5 core questions, continued

1. What is the condition of my assets?
   - *Why* should we assess condition?
   - *How* do we assess condition?
   - What are the *four major failure modes*?

AM plan 10-step process

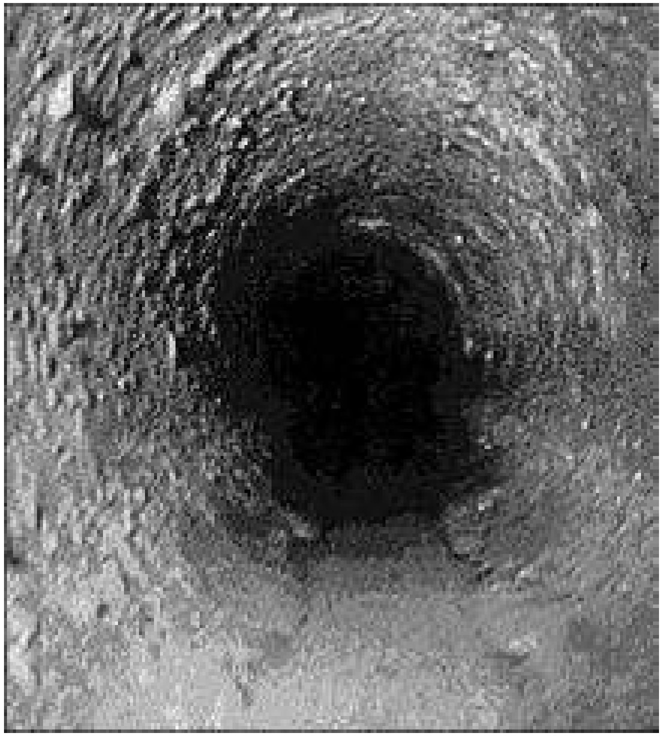
Condition Assessment Protocol; Rating Methodologies

1. What is the current state of my assets?

Develop Asset Registry → Assess Condition, Failure Modes → Determine Residual Life → Determine Live Cycle & Replacement Costs → Set Target Levels of Service (LOS)

→ Determine Business Risk (“Criticality”) → Optimize O&M Investment → Optimize Capital Investment → Determine Funding Strategy → Build AM Plan

All assets deteriorate and eventually fail



Pipe sediment build-up progressively constricts flow and reduces service

Cleaning and relining restores service and extends useful life, perhaps 50 years

Condition guides timing of *maintenance and renewal investment*

Fundamental principle of condition assessment

Condition assessment is important only to the extent it provides insight into…

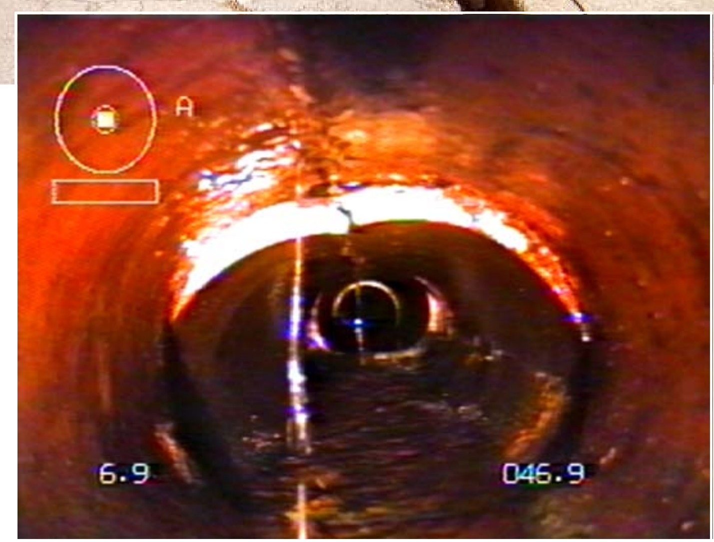
- *Nature* of possible failure
  - Root cause
  - Pattern (shape of the deterioration curve)
- *Timing* of possible failure (residual functional life)

Typical condition assessment techniques

- Visual inspection
- Non-destructive testing
- Destructive testing

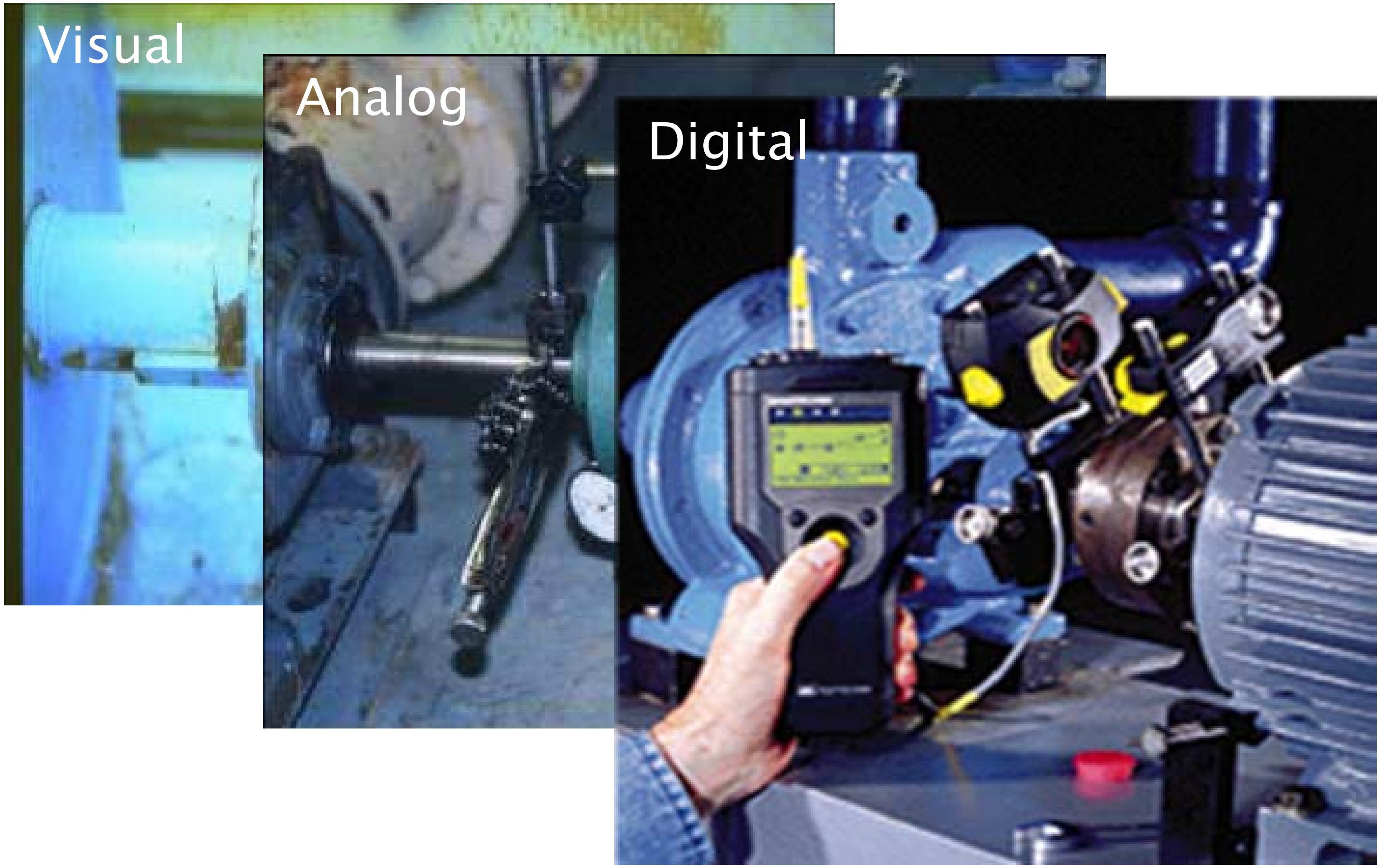
Methods to assess collection system conditions

- Smoke testing
- Dye testing
- Lamping
- Video inspection (CCTV)
- Sonar
- Ground-penetrating radar



CCTV is closed-circuit television

Evolution of condition technology



More condition information, faster, at lower cost from technological advances

Early forms of condition definition and ranking

Example One

Condition Class 1	Damage to be repaired immediately
Condition Class 2	Damage to be repaired within 1 year
Condition Class 3	Damage to be repaired within 3 years
Condition Class 4	Damage to be repaired within 7 years
Condition Class 5	Damage to be repaired in the course of other construction work
Condition Class 6	No damage

Early forms of condition definition and ranking

Example Two

1. *Urgent repairs*

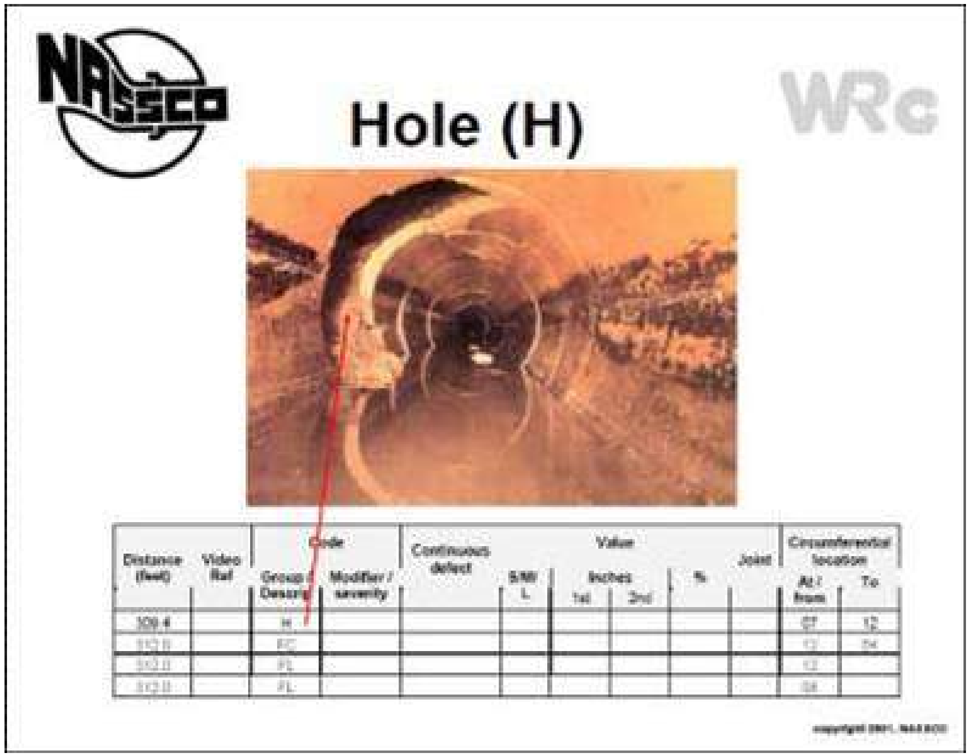
   To meet emergency situations
   To meet legal requirements
2. *Necessary repairs*
   To eliminate safety hazards and code violations
   To meet contractual obligations
   To perform required renovations and repair
3. *Desired repairs*
   To replace equipment
   To extend or enhance service
   To match funds
4. *Ongoing repairs*
   To continue work in progress
5. *Deferrable repairs*
   To perform non-essential renovations/improvements
   To perform projects with questionable need or with timing problems

More evolved form of condition ranking system

- Pipe Rise/Joint Offset
  1. Minor – not critical
  2. Moderate – not critical to flow pattern
  3. Significant – possible infiltration source
  4. Severe – pipe offset impeded/obstructed flow, probable infiltration source
- Pipe Dip
  1. Length 0-10 feet – not critical
  2. Length 11-20 feet – causes minor velocity reductions
  3. Length 21-30 feet – causes solids to settle in pipe
  4. Length >31 feet – can cause significant solids buildup
- Joint Infiltration
  1. Slow drip
  2. Steady drip
  3. Continuous flow – moderate
  4. Continuous flow – severe
- Mineral Buildup (at joint)
  1. Deposit on wall without any noticeable flow restriction – not critical
  2. 0.25 Reduction in pipe diameter, some flow restriction
  3. 0.25-0.5 Reduction in pipe diameter, significant flow restriction
  4. >0.5 Reduction in pipe diameter, camera unable pass – severe flow Reduction
- Laterals with Roots (house lateral)
  1. Some root penetration – no blockage
  2. More established root presence – minimal blockage
  3. 0.5 of lateral is blocked – possible infiltration and flow restriction
  4. Near total blockage – probable infiltration and flow restriction
- Joints with Roots
  1. Some root penetration – no blockage
  2. More established root presence – minimal blockage
  3. 0.5 of pipe blocked – possible infiltration and flow restriction
  4. Near total blockage – probable infiltration and flow restriction
- Pipe Break
  1. Minor Break – no structural impairment
  2. Break with separation – structural impairment not immanent
  3. Break with separation/partial collapse immanent structural failure
  4. Severe breakage requiring immediate attention to maintain flow
- Debris Blocking Pipe
  1. Minor debris – minimal flow restriction
  2. Moderate debris – minor flow restriction
  3. Significant debris – moderate flow restriction
  4. Severe debris – near total flow restriction
- Pipe Cracks
  1. Hairline no structural impairment
  2. Crack with separation structural impairment not immanent
  3. Crack with separation/partial collapse immanent structural failure
  4. Severe crack requiring immediate attention to maintain flow
- Lateral protrusion
  1. <1" minimal flow restriction
  2. >1" moderate but not critical to flow pattern
  3. 0.5-0.75 full pipe blocked – severe flow restriction
  4. 0.75 full pipe blocked – severe flow restriction

Emerging national standards for pipes

Pipe Assessment Certification Program (PACP)



From National Assoc. of Sewer Service Companies (NASSCO)
& Water Research Center (WRC), *Manual of Defect Classification*

Emerging national standards for pipes

*Structural defect scores - Pipe sewers

Defect	MSCC Code	Description	Score
Longitudinally displaced joint / Open joint	OJM	Medium < 1"pipe thickness	1
	OJL	Large > " pipe thickness	2
		If soil visible grade as a hole	165
Radially displaced joint	JDM	Medium < 1" pipe thickness	1
	JDL	Large > 1" pipe thickness	2
		> 10% diameter & soil visible	80
Cracked	CC	Circumferential	10
	CL	Longitudinal*	10
		Complex*	40
		Helical*	40
	CM		
Fractured	FC	Circumferential	40
	FL	Longitudinal*	40
		Complex*	80
		Helical*	80
	FM		
Broken	B		80
Hole	H	Radial extent <¼	80
		Radial extent ¼+	165
Collapsed	X		165

*Abstract from Sewerage Rehabilitation Manual (Fourth Edition)

From National Assoc. of Sewer Service Companies (NASSCO)
& Water Research Center (WRC), *Manual of Defect Classification*

Condition assessment protocol (CAP)

Which assets? What information? How used?

CAP 1	Simple scoring system, e.g., 1-5, or 1-10
CAP 2	Matrix scoring system with multiple distress factors and weightings to derive a score
CAP 3	Use of sophisticated techniques to determine the *residual life to intervention* or end of physical life

Characteristics of a good CAP

- Focused on *remaining useful life*, rather than just condition score
- Carefully defined, with good written protocol
- Built around *business risk assessment* (of critical assets)
- Consistently applied (across time, across inspectors)
- Cost effective, using smart *data collection techniques*

Example *CAP 1*

Score	*Description*	*Maintenance Level*	*Percent Replacement*
0	New	Normal	0
1	Perfect/excellent condition	Normal	0
2	Minor defects only	Minor	5
3	Backlog maintenance required	Significant	10-20
4	Major renewal required	Renew	20-40
5	Asset nearly unserviceable	Replace	>50

Example of expanded *CAP 1.5*

Refining CAP scale to fit relative distress of assets

6-Point Scale	***Expanded 6-Point Scale***
0	4.0
1	4.1
2	4.2
3	4.3
4	4.4
5	4.5
	4.6
	4.7
	4.8
	4.9
	5.0

CAP is condition assessment protocol

Example *CAP 2*

Distress Mode	*Rating (1-5)*	*Weighting (1-3)*	*Score*
Corrosion	3	3	9
Vibration	1	1	1
Leakage	2	1	2
Heat	4	2	8
Performance	2	3	6
Noise	1	1	1
		Condition Rating	27
		Normalized Rating (27/90)	30

Example *CAP 3*

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CITY OF PHOENIX - 24th STREET WATER TREATMENT PLANT

ASSET CONDITION RELIABILITY ASSESSMENT RATING TABLES

Conventional Pumps

Inclusion: Dry well & line shaft pumps Dosing Pumps

Makes use of vibration, sonic, thermal, electrical, oil residue, electromagnetic, and performance signatures—or information

	Aspect	Distress Mode	Rating 1	Rating 2	Rating 3	Rating 4	Rating 5
CONDITION ASSESSMENT							
C	Use	Motor Hours Run	< 10,000	> 10,000	> 50,000	> 100,000	> 200,000
D	Symptoms	Vibration	No unusual vibration detectable	Minor vibration detected	Moderate vibration	Considerable vibration (wristwatch shakes)	Major vibration
E		Temperature	No unusual temperature detected	Minimal heat from casing using hand	Heat detected by hand	Heat detected by hand is uncomfortable	Heat too high to assess by hand
F		Noise	No unusual noises detected.	Slight whine/rattle detected.	Moderate whine/rattle detected, easily heard over pump noise.	Loud whine/rattle.	Disturbingly loud operation/vibrations.
RELIABILITY ASSESSMENT							
A	Unplanned Outages	Avg No./Year	0 / Year	< 2 / Year	< 5 / Year	< 10 / Year	> 10 / Year
B	Efficiency	Flow Output	Flow within 5% of duty point.	Flow within 10% of duty point.	Flow within 20% of duty point.	Flow within 40% of duty point.	Flow > 40% of duty point.

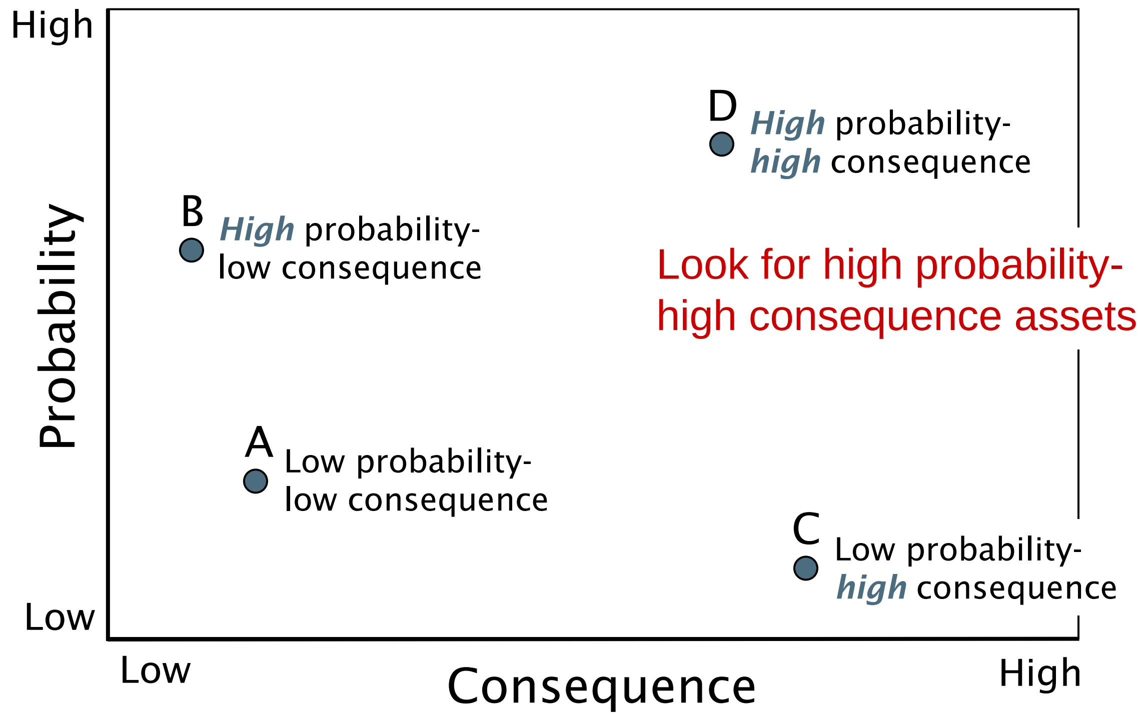
Seven smart ideas for condition data collection

1. *Business risk-driven,* with focus first on high risk, high consequence assets
2. *Problem assets-profiled*, noting that 20% of assets cause 80% of problems
3. *Sampling approach*
4. *Stepped approach*, applying more sophisticated assessment techniques to higher-cost, higher business risk-assets
5. *Failure mode-guided*, do I need condition data?
6. *Root cause-driven,* (Bayesian probability, SCRAPS)
7. *Valued judgment/Delphi approach*, as supplement to minimal data

BRE is business risk exposure; SCRAPS is Sewer Cataloging, Retrieval, and Prioritization System

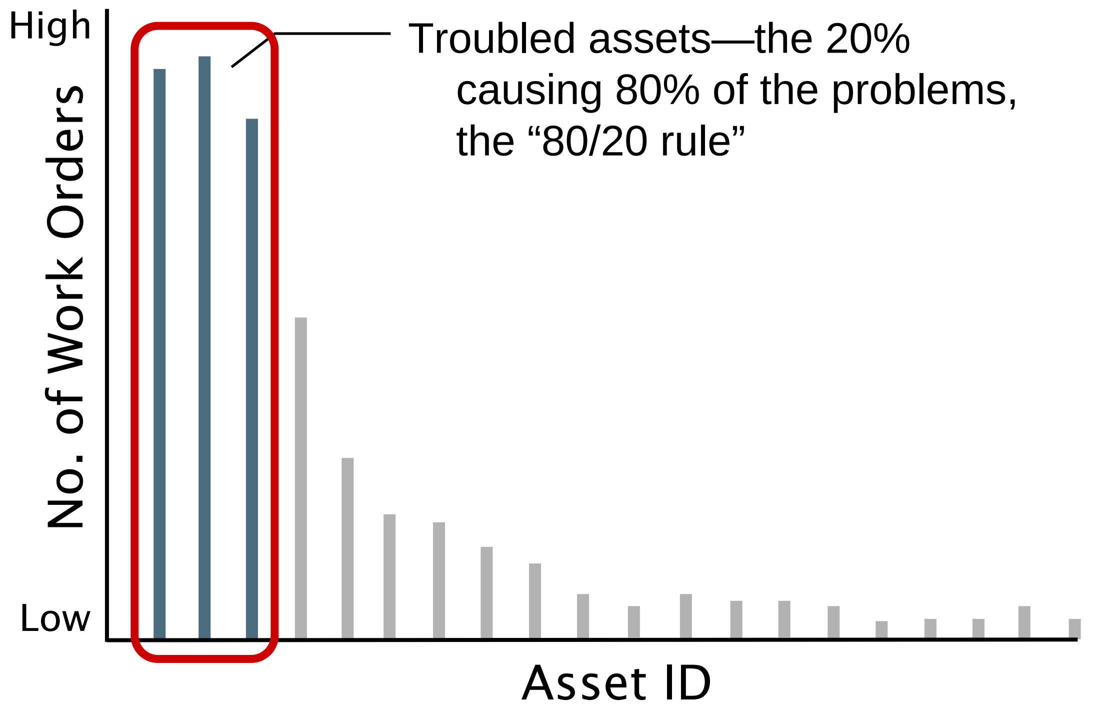
Idea 1, business risk-driven

What is probability of failure? What is consequence of failure?



Idea 2, problem assets-profiled

Do we know which are our problem assets?



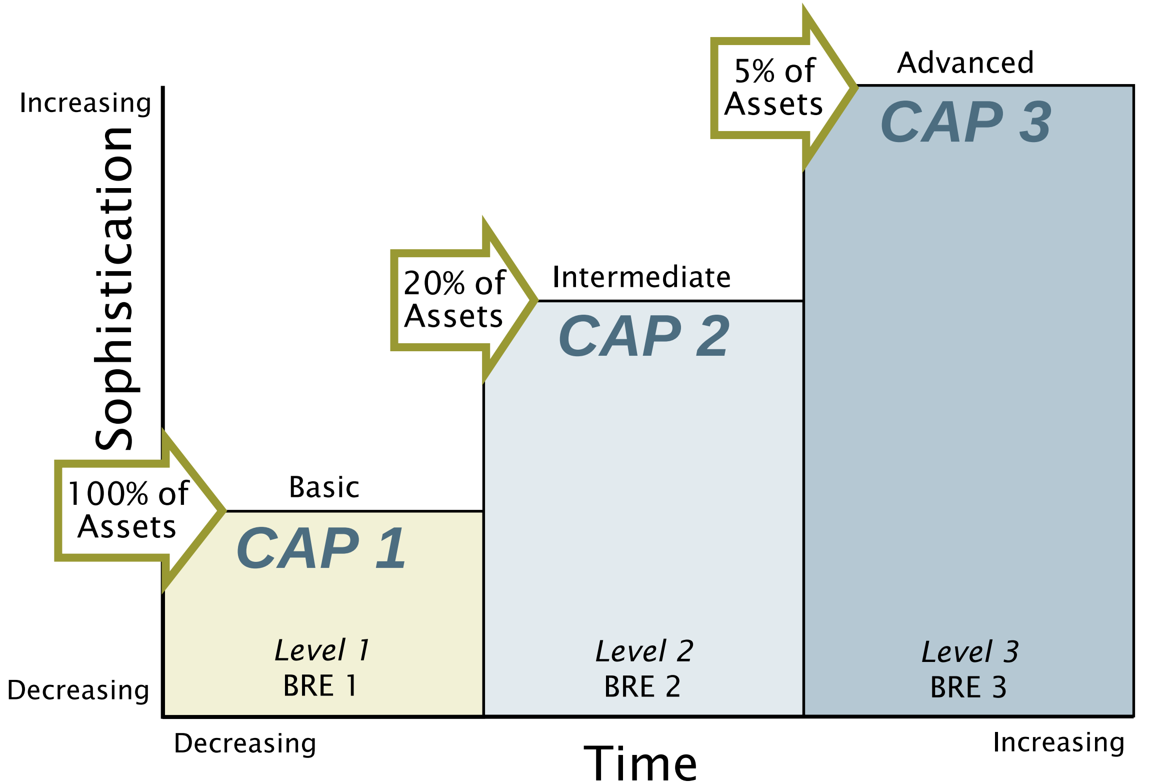
Idea 3, sampling approach

Statistically-sound, validated sampling can render high level of decision confidence at relatively low cost…

- Using *larger* sample size for *more critical* assets and *smaller* size for *less critical*
- Building sample collection around *root causes* of failure—understanding your *failure modes*

Idea 4, stepped approach

Levels of sophistication in condition assessment



BRE is business risk exposure, CoF is consequence of failure, PoF is probability of failure, MTBF is mean time between failures

Idea 5, failure mode-guided

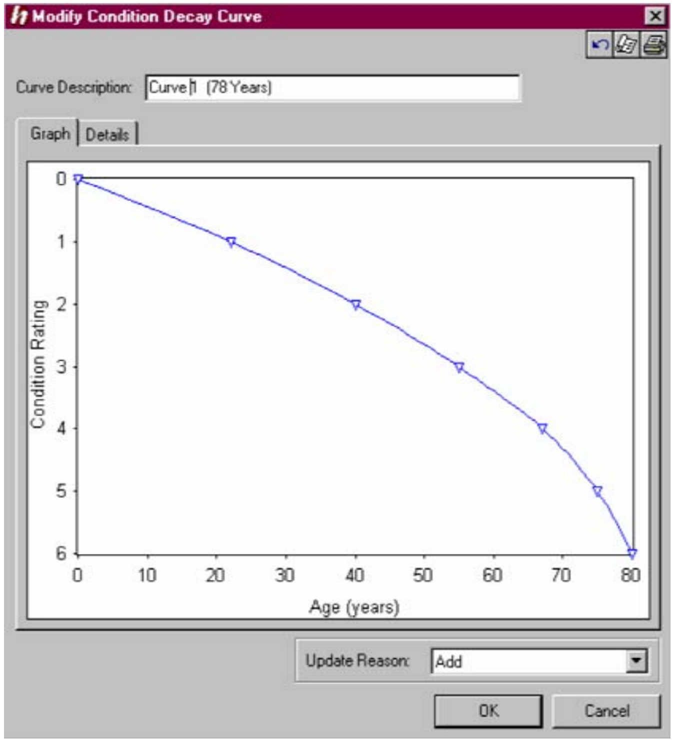
Failure Mode	*Definition*	*Tactical Aspects*	*Management Strategy*
Capacity	Volume of demand exceeds design capacity	Growth, system expansion	(Re)design
LOS	Functional requirements exceed design capability	Codes & permits: NPDES, CSOs, OSHA, noise, odor, life safety; service, etc.	(Re)design
Mortality	Consumption of asset reduces performance below acceptable level	Physical deterioration due to age, usage (including operator error), acts of nature	O&M optimization, renewal
Efficiency	Operations costs exceed that of feasible alternatives	Pay-back period	Replace

NPDES is National Pollutant Discharge Elimination System, CSOs are combined sewer overflows, and OSHA is Occupational Safety and Health Administration

Condition assessment and the decay curve

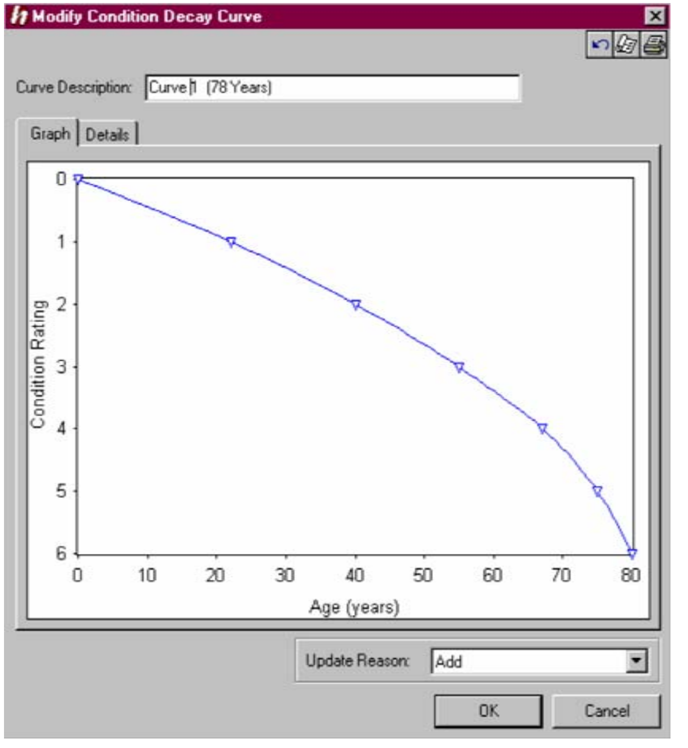
Condition assessment assists in recognizing…

- *Nature* and *shape* of the failure or decay (or deterioration) curve
- *Where* on the curve is asset's current condition
- Asset's *remaining useful life*, an estimate

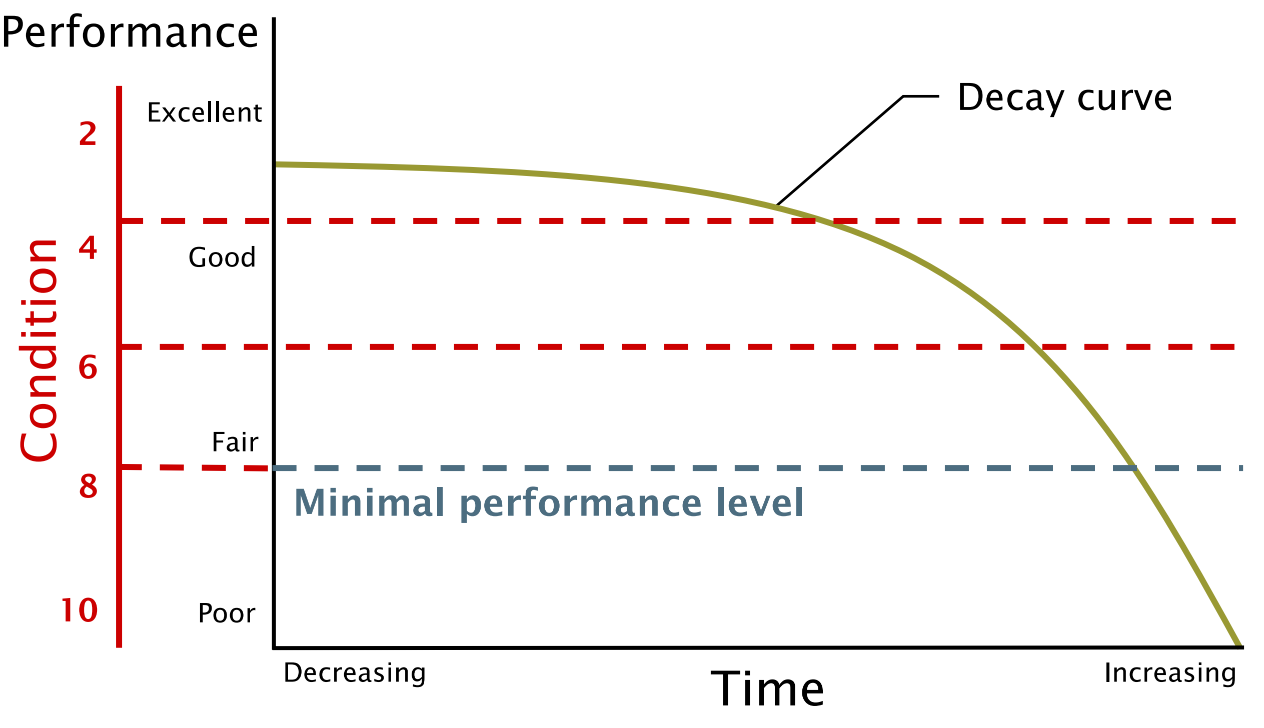


Developing a decay curve

- *Longitudinal* study—uses data collected *over the life* of a *single* asset (or set of assets)
- *Latitudinal* study—uses data collected from *multiple* assets of the same type but of different ages



Tying condition score to asset failure



Idea 6, root cause-driven (Bayesian)

- *"Valued judgment"* is used to assign *failure variables and propositions* (sequence of causes of failure)
- *"Valued judgment"* is used to assign *conditional probabilities* (likelihood of occurrence)
- *"Causal path"* networks are developed relating *"root cause"* to functional failure
- *Probabilities* are assigned to each of the path elements

What is SCRAPS?

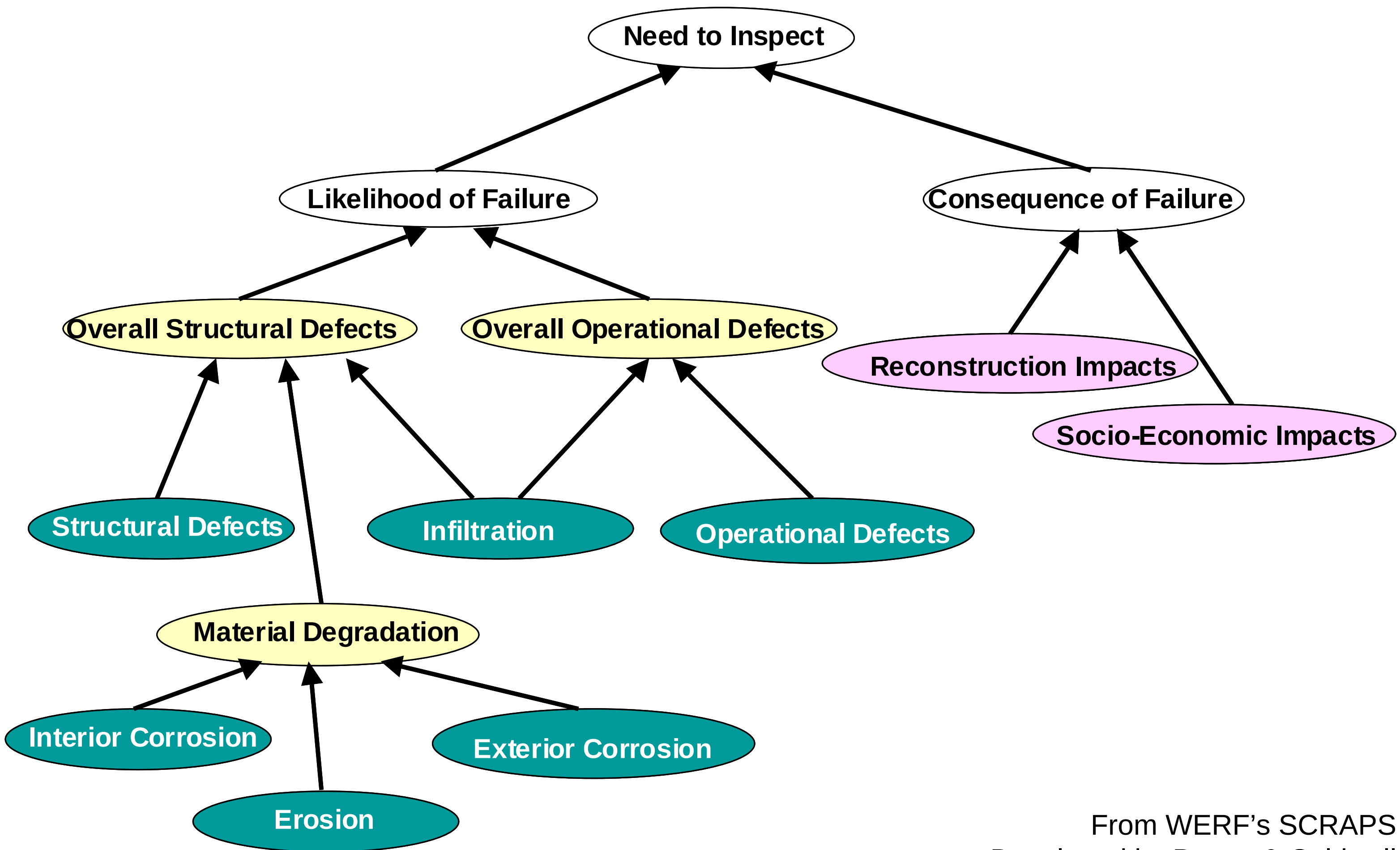
Sewer Cataloging, Retrieval, and Prioritization System (SCRAPS)

Courtesy of WERF and Brown & Caldwell

Example of Bayesian probability

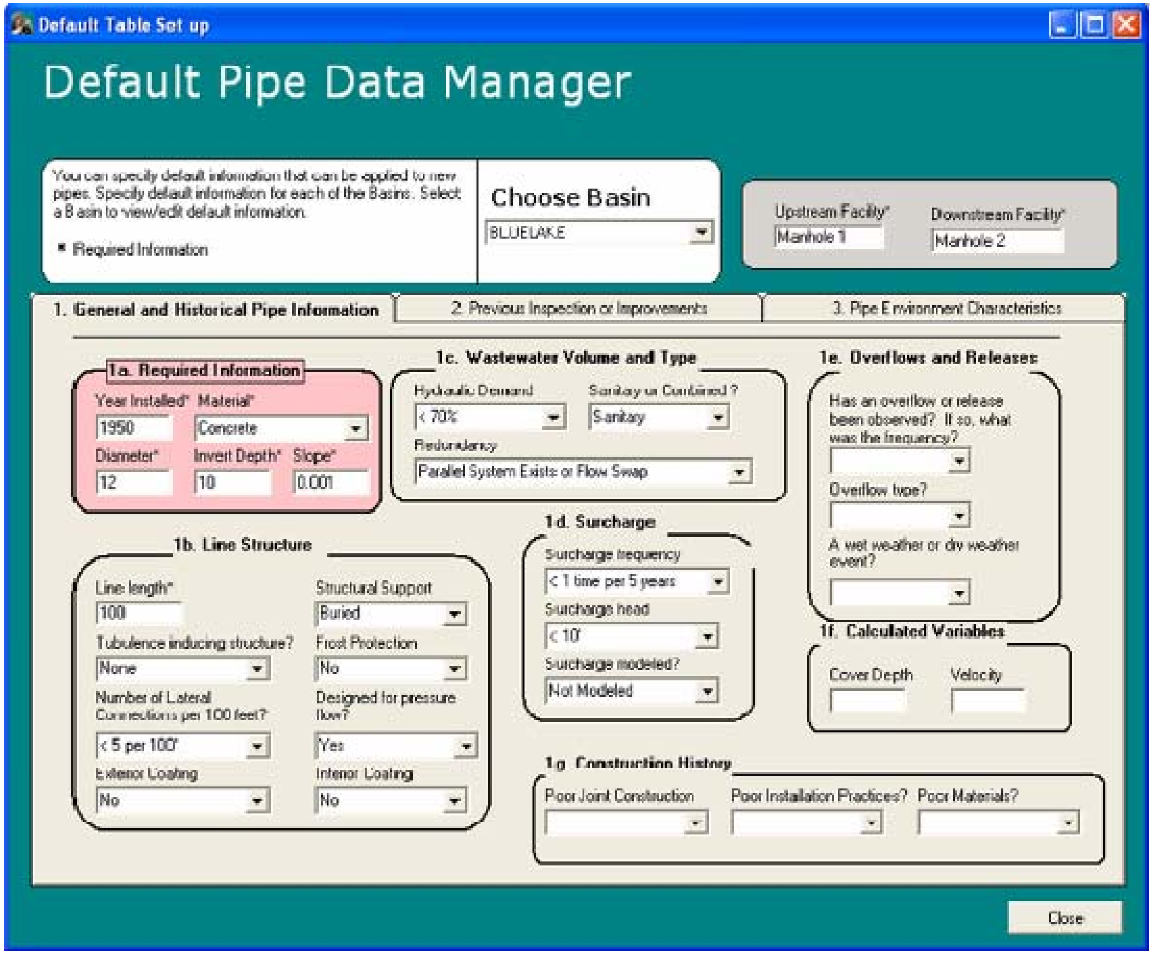
- *Proposition:* Sewer joint failures are common when the sewer is in marshy soil without support
- Or, equivalently, in Bayesian terms
  - If probability of marshy soil is *high*
  - And probability of sufficient support is *low*
  - Then *probability of joint failure is high*

SCRAPS Bayesian logic structure



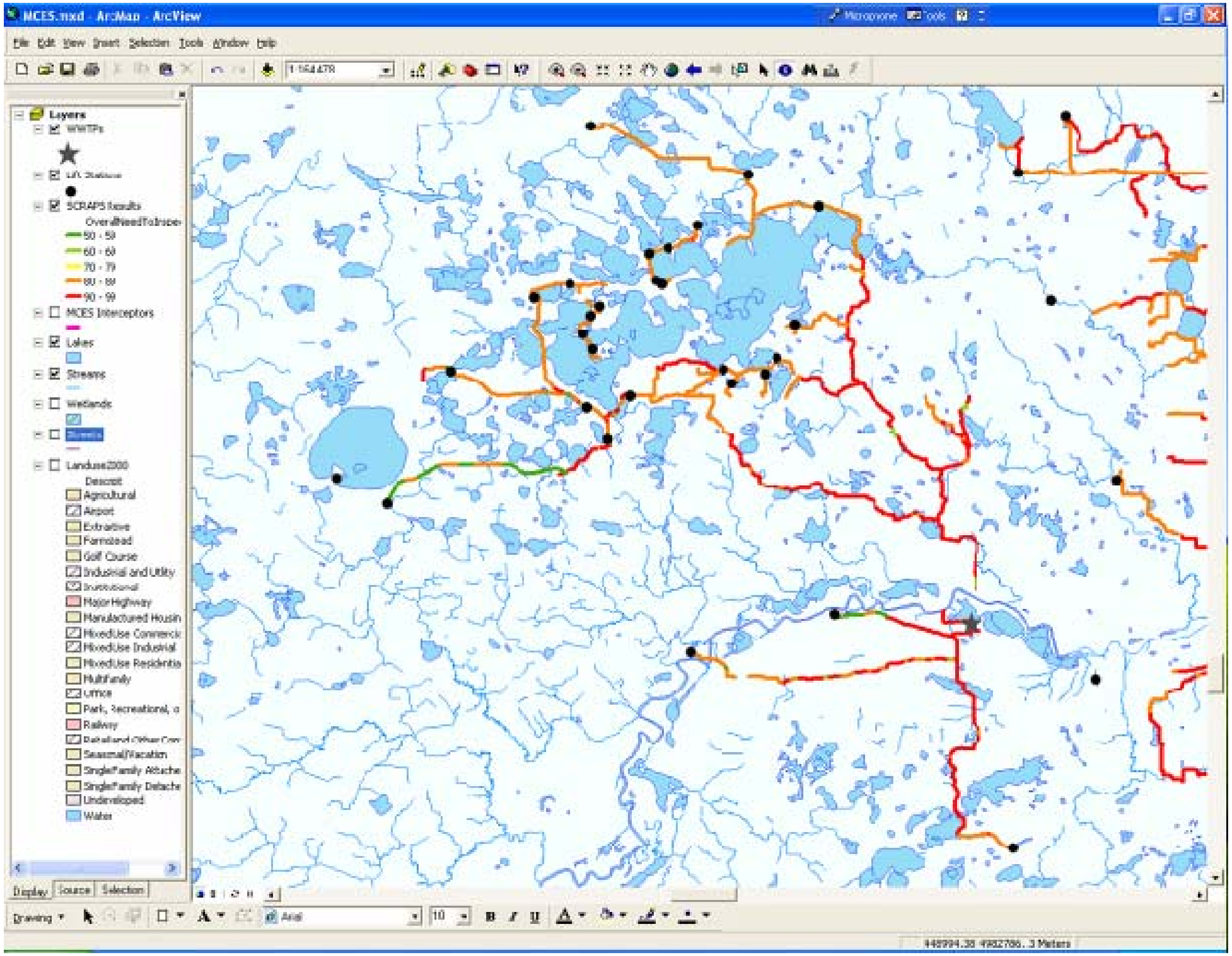
From WERF's SCRAPS
Developed by Brown & Caldwell

Default data manager



Courtesy of WERF and Brown & Caldwell

View of pipe information from SCRAPS



Courtesy of WERF and Brown & Caldwell

Idea 7, valued judgment/Delphi approach supplements minimal data

"Valued judgment" is used to assign condition scores

- Assemble team of most-knowledgeable personnel
- Poll each member for opinion on condition score and why
- Augment with work order data and failure patterns
- Use photos and process schematics
- Facilitate group consensus through discussion

Important note on condition assessment

- Condition assessment is not an end in itself, but is a *means* to an end
- The *end* is to determine *remaining useful life*
- *Good-Fair-Poor*-type ratings have little utility *unless* they lead to an effective estimate of remaining useful life

The remaining useful life of an asset is *what we have left to try to manage*

Key points from this session

What condition is it in?

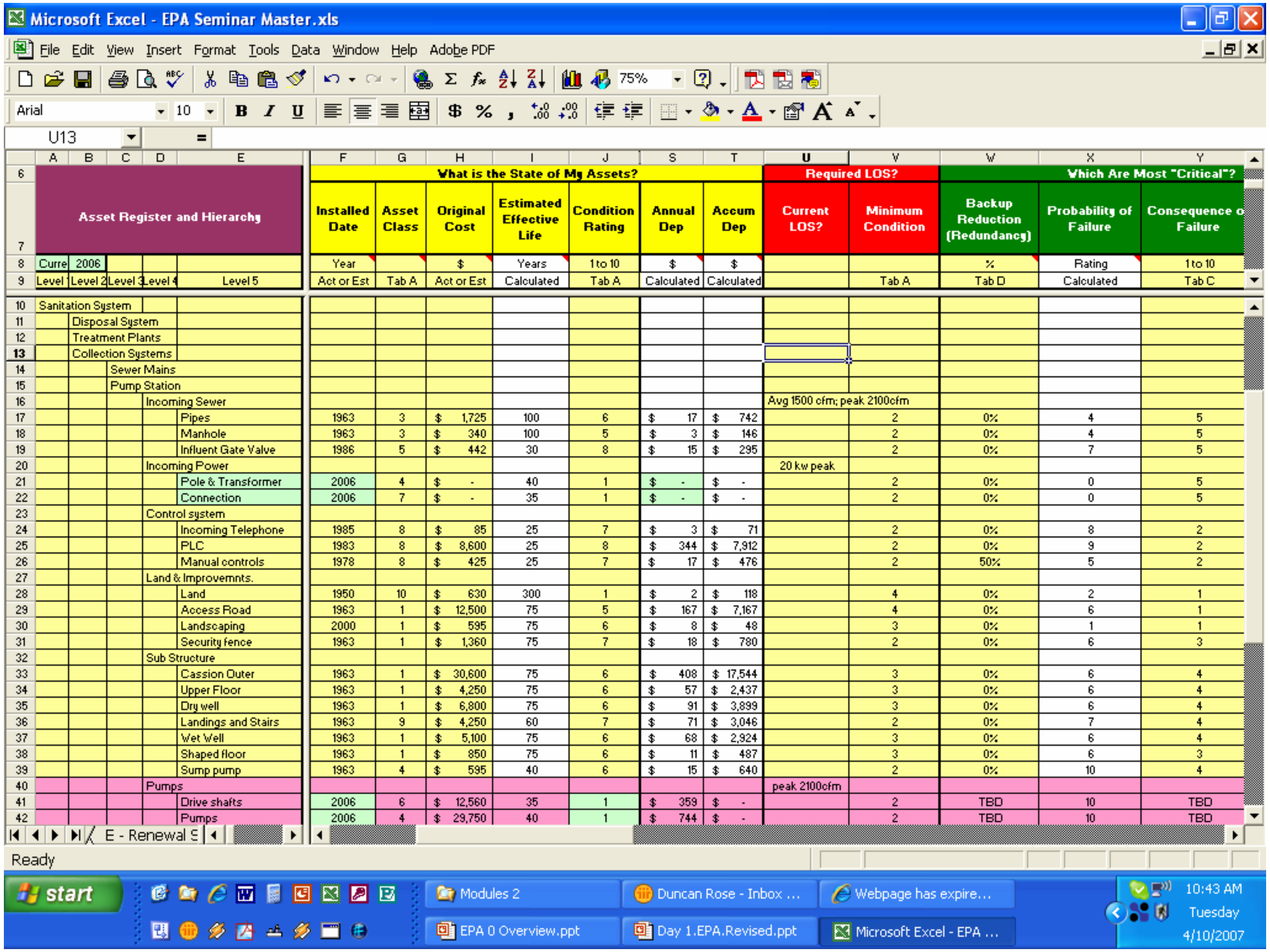
Key Points:

- Condition assessment rating scales must project remaining useful life to be useful for decision-making
- To be most cost-effective, condition assessment must be guided by the same core concepts that guides all AAM – “failure modes” and the likelihood and consequences of failure

Associated Techniques:

- Condition assessment technology
- Condition rating protocol

Tom’s spreadsheet



Row	Asset Register and Hierarchy	Installed Date	Asset Class	Original Cost	Estimated Effective Life	Condition Rating	Annual Dep	Accum Dep	Current LOS?	Minimum Condition	Backup Reduction (Redundancy)	Probability of Failure	Consequence of Failure
6		What is the State of My Assets?							Required LOS?		Which Are Most "Critical"?		
8	Curre 2006	Year		$	Years	1 to 10	$	$			%	Rating	1 to 10
9	Level 1 / Level 2 / Level 3 / Level 4 / Level 5	Act or Est	Tab A	Act or Est	Calculated	Tab A	Calculated	Calculated		Tab A	Tab D	Calculated	Tab C
10	Sanitation System												
11	Disposal System												
12	Treatment Plants												
13	Collection Systems												
14	Sewer Mains												
15	Pump Station												
16	Incoming Sewer								Avg 1500 cfm; peak 2100cfm				
17	Pipes	1963	3	$ 1,725	100	6	$ 17	$ 742		2	0%	4	5
18	Manhole	1963	3	$ 340	100	5	$ 3	$ 146		2	0%	4	5
19	Influent Gate Valve	1986	5	$ 442	30	8	$ 15	$ 295		2	0%	7	5
20	Incoming Power								20 kw peak				
21	Pole & Transformer	2006	4	$ -	40	1	$ -	$ -		2	0%	0	5
22	Connection	2006	7	$ -	35	1	$ -	$ -		2	0%	0	5
23	Control system												
24	Incoming Telephone	1985	8	$ 85	25	7	$ 3	$ 71		2	0%	8	2
25	PLC	1983	8	$ 8,600	25	8	$ 344	$ 7,912		2	0%	9	2
26	Manual controls	1978	8	$ 425	25	7	$ 17	$ 476		2	50%	5	2
27	Land & Improvemnts.												
28	Land	1950	10	$ 630	300	1	$ 2	$ 118		4	0%	2	1
29	Access Road	1963	1	$ 12,500	75	5	$ 167	$ 7,167		4	0%	6	1
30	Landscaping	2000	1	$ 595	75	6	$ 8	$ 48		3	0%	1	1
31	Security fence	1963	1	$ 1,360	75	7	$ 18	$ 780		2	0%	6	3
32	Sub Structure												
33	Cassion Outer	1963	1	$ 30,600	75	6	$ 408	$ 17,544		3	0%	6	4
34	Upper Floor	1963	1	$ 4,250	75	6	$ 57	$ 2,437		3	0%	6	4
35	Dry well	1963	1	$ 6,800	75	6	$ 91	$ 3,899		3	0%	6	4
36	Landings and Stairs	1963	9	$ 4,250	60	7	$ 71	$ 3,046		2	0%	7	4
37	Wet Well	1963	1	$ 5,100	75	6	$ 68	$ 2,924		3	0%	6	4
38	Shaped floor	1963	1	$ 850	75	6	$ 11	$ 487		3	0%	6	3
39	Sump pump	1963	4	$ 595	40	6	$ 15	$ 640		2	0%	10	4
40	Pumps								peak 2100cfm				
41	Drive shafts	2006	6	$ 12,560	35	1	$ 359	$ -		2	TBD	10	TBD
42	Pumps	2006	4	$ 29,750	40	1	$ 744	$ -		2	TBD	10	TBD